Totem: The University of Western Ontario Journal of Anthropology

Volume 8 | Issue 1 Article 8

6-21-2011

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Keywords
craniometric analysis, forensics, methodology, history

A MEASURE OF TRUTH? AN EXAMINATION OF THE HISTORY, METHODOLOGY, THEORY AND PRACTICE OF CRANIOMETRIC ANALYSIS: WITH SPECIAL FOCUS ON ITS APPLICATION IN FORENSIC IDENTIFICATION

Christianne Stephens

The resurfacing of heated debates regarding the applicability of craniometry to anthropologicalresearch (particularly as a diagnostic tool for sex and race determination) have left many anthropologists and novices in the field questioning the role of science in the sphere of physical anthropology. The history of craniology and its subdiscipline craniometry are built upon (as is the case in all academic disciplines) a plethora of names representing the pioneering innovators of the methods and theories of the discipline. Indeed, the material explaining the methodology used in the field is detailed, complex at times, and would justifiably take up the entire length of this essay.

Therefore, the goal of this paper is to acquaint the reader with the discipline of craniometry by providing a basic overview of the following four themes: 1) the history and standardisation of craniometry; 2) the application of statistical analysis to craniometric data; 3) the introduction of computer-based analysis to sex and race determination; and 4) present-day innovations in the field of forensic anthropology including the Forensic Data Bank, the computer program FORDISC 2.0 and the achievements and limitations of craniometric analysis as they relate to the field of forensic anthropology. The fourth theme of this series will be augmented with a simple test experiment involving craniometric data and multivariate discriminant functions analysis as processed by the newly conceived forensic identification computer program.

THE HUMAN CRANIUM: DOME OF THOUGHT, PALACE OF THE SOUL AND MODEL FOR SCIENTIFIC DISCOURSE

In *The Magic of the Skull: Commercium Craniorum in the Nineteenth Century (1997: 571-574),* A. M. Luyendijk-Elshout traces the germs of thought that would transform the mystified human skull into a scientific tool of learning and progress. Johann Friedrich Blumenbach (1752- 1840) is credited as being one of the pioneer collectors of cranial specimens beginning in the late eighteenth century. Ultimately, international congresses of researchers (including anthropologists) soon became marketplaces for the procurement and exchange of sought-after cranial material, particularly "skulls of exotic tribes, such as those of the Peruvians or inhabitants of the Pacific Islands" (Luyendijk-Elshout 1997:572). The intellectual agora of human crania, referred to by Luyendijk-Elshout as "*The Commercium Craniorum*" functioned via a nexus of networking researchers, anthropologists and phrenologists; individuals whose system of bartering and selling cranial material allowed for the compilation of several collections of crania around the world.

As "exotic" and didactically significant a cranium of diverse ancestry may have been to anthropological comparative studies during the nineteenth century, the standard to which all specimens were measured (and consequently labeled as inferior to) was that of the Caucasian skull. Following Blumenbach's statement that the human skull should be "studied as a portrait" (Luyendijk-Elshout 1997:572), the conceived differences between intellect, civility, progress and morality were often pictorially represented through the juxtaposition of hellenised Caucasian physiognomy with that of pithecanthropine-depicted "Negro" caricatures, as pseudoscientific theories concerning the relationship between head proportion and brain size began to crystallise. Biological determinism and questions regarding the inferiority of certain races and individuals also crosscut into gender studies, particularly in the area of intellectual differences between the sexes. Hence, the positive centripetal force of inquiry that had originally inspired early natural scientists into the realm of cranial studies began to proceed in another direction, this time propelled by the inner centrifugal forces of researchers' own prejudices and misinterpretations of biological diversity.

THE DISCIPLINE AND STANDARDISATION OF CRANIOMETRY

The roots of anthropometry are traced back to the initial measurement of the skull by early scientists. Simply defined, craniometry refers to "the study of human cranial measurements for use in anthropological classification and comparison" (The Skeptic's Dictionary 1998). The standardisation of craniometry was the result of a collective effort of international anthropologists which included "Virchow and Ranke in Germany, Flower and Turner in England and Broca in France" (Rogers 1984:36) and as the result of an 1882 conference in Frankfort, Germany, a consensus was reached by attending anthropologists regarding craniometric measurement standards and practices (Rogers 1984:36). The next several decades would witness several revisions to the original standards along with a fair share of criticism, most of which resonated the strongly held opinion that "measurements of the skull [have] little value as determiners of race affiliation" (Rogers 1984:114). The negative precedence set by early anthropologists who employed cranial measurements as scientific justification for racial discrimination and sexism have tainted the history and legitimacy of craniometry with charges of relativism, political motivation and scandal. Rogers deflects the skepticism spurred by the distant and recent past by emphasising the potential of craniometry in future research studies related to anatomy and variation, human life cycle studies, the research of pathological conditions, the forensic sciences and archaeological studies of the biological affinity, demography, nutrition and disease of ancient populations (Rogers 1984:37).

The ability to take accurate cranial measurements is determined by the following factors: 1) availability of necessary cranial specimens; 2) access to required laboratory equipment and knowledge of their proper use; 3) knowledge of the anatomical nomenclature of cranial landmarks and the ability to identify their location on cranial specimens; 4) familiarity with the conventional measurements of the skull and the significance of these measurements; and 5) ability to pay strict attention to detail in data collection and recording procedures.

FROM MEASUREMENTS TO STATISTICS: THE PRELIMINARY APPLICATION OF MATHEMATICAL ANALYSIS TO CRANIOMETRIC DATA

The somewhat awkward relationship between statisticians and anthropologists, according to Corrucini (1984:13) stems from the fact that the former "speaks in a mathematical language while the latter speaks in a biological language". In reality, most contemporary anthropologists tend to agree that the biological variation that exists between individuals and populations inhibits the neat taxonomy of people into definite classifications based upon morphological characteristics alone. Because of this, the interpretation of osteometric data such as those derived from cranial measurements have proven difficult to express in the "black and white", quantitative framework of statistical science. Logistic and practical difficulties (particularly the challenge posed to physical anthropologists by demanding mathematical calculations) illustrate the reasons why the parallel progress uniting statistics and anthropology is viewed as being "a reciprocal advancement which [has been] necessary but difficult" (Howells 1984:1). However, the obvious benefits reaped from the interaction collaborative exchange between both disciplines must not go unrecognized. If it were not for the introduction of statistical methodology to the discipline of physical anthropology, "caliper anthropologists" (as they were commonly referred to in the early 1930's and 40's) (Howells 1984:2) would have become obsolete, more than likely floundering within the academic milieu at the time which held true to the belief that "in general, measurements (including cranial measurements) would form a far smaller part of anthropological activity in the future" (Washburn 1952:714-728). The survival of craniometry as a "legitimate science" is attributed to the pioneering work of Pearson (1926), Barnard (1935) and Fisher (1936), while the adoption of statistical methods used in the field of psychology became a model that set the groundwork for discourse, analysis and representational framework for the interpretation of modern craniometric data.

THE GILES AND ELLIOT MODEL FOR SEX AND RACE DETERMINATION THROUGH DISCRIMINANT FUNCTIONS ANALYSIS

A function is "a mathematical correspondence that assigns exactly one element of one set to each element of the same or other set " (Webster's Dictionary 1979:461). R.A. Fisher is acknowledged as having first introduced the concept of multivariate discriminant functions analysis to anthropological research (Barnard 1935:352-372), while techniques built upon this method by Giles and Elliot in the early 1960s elevated the applicability, comprehensibility and feasibility of sex and race determination by metrical means to a higher level of study. In their well-known article *Sex Determination by Discriminant Functions Analysis of Crania (1963:53-68),* Giles and Elliot demystify the concept and usage of mathematical formulae employed in discrimiminant functions analysis through a lucid description of the foundations upon which this method is based. They begin their discourse by explaining the concept of regression analysis, defined as "the prediction of the value of one variable from the values of other given variables " (Giles and Elliot 1963:54). In layman's terms, linear regression is representative of the relationship between two variables, one being of a dependent nature, the other being of an independent nature (Giles and Elliot 1963:54). The authors reinforce the logistics of this concept by offering as an example the practice of stature estimation from a human femur (1963:54). In this case, the independent variable is the femur while the dependent variable is stature, a designation which is based upon the reality that the former value is dependent due to the fact that the end-result of stature depends upon the value attained by the independent growth of the femur. Represented by the formula **y= a+bx, y** represents the dependent variable (stature), **x** stands for the value of the independent variable (that of the femur), while **a** and **b** represent the coefficients that "provide the best prediction of **y** from **x**"(Giles and Elliot 1963:54). Multiple functions analysis can be viewed as conforming to the same scheme of linear regression, with the only difference being that multiple functions analysis involves the regression of "one dependent variable to multiple independent variables" (Giles and Elliot 1963:54).

SEX DETERMINATION

According to Rathbun and Buikstra (1984:240-241), there is a distinct procedure to the application of multiple discriminant functions analysis, as it is utilised in the anthropological study of sex determination. First and foremost, specimens undergoing sex determination must be of known racial ancestry as "different" formula weights are used for different racial groups. Each gender is then assigned an arbitrary value (such as 0 for males and 1 for females) for the purpose of illustrating that sex is "an artificial, dependent variable" (Rathbun and Buikstra 1984:240) which is dependent upon independent, individual measurements. A list of measurements is then recorded for the specimen. Most often, the measurements taken include: cranial length, cranial breadth, mastoid height and post-cranial measurements. Each measurement is assigned a corresponding "weight" (coefficient) (based on computer calculations first determined by Kendel in 1957) in the discriminant functions' formula after which measurements are multiplied by their weighted scores resulting in a series of "products". By adding the products derived from an individual's many measurements, a single numerical value known as the *discriminant functions score* is calculated. This score (which serves to "replace" a host of measurements for an individual) is "divided into two groups with little overlap" (Rathbun and Buikstra 1984:54). The mean function scores for either sex can be established by substituting for example, the "mean male value of each measurement into the discriminant function" (Rathbun and Buikstra 1984:54). This results in the creation of a dividing line, known as a *sectioning point* which is expressed as a numerical value and serves as the arithmetically-derived schism that enables the anthropologist to distinguish between male and female specimens. In general, males express a higher numerical reading (falling above the delineated sectioning point) than females, whose lower numerical values cause female specimens to fall beneath the delineated sectioning point.

Giles and Elliot formulated their discriminant functions based on measurements taken from skeletal materials belonging to both the Hamann-Todd and Terry Collections. Nine measurements taken from each cranium making up their 408 known-sex Caucasoid and Negroid sample were recorded and later calculated into 21 different combinations to form the discriminant functions. Sexing of Negroid and Caucasoid crania using the discriminant functions calculated from these measurements resulted in an 85-89% accuracy rate (Giles and Elliot 1963:67). Native American samples were represented by three collections of Native American crania originating from Indian Knoll (a Native American site in West Kentucky dated by radiocarbon approximately 3450 B.C.), north-central New Mexico (a series of Native American Crania from Pecos Pueblo dated to around A.D. 1300) and Native American samples from Florida (in the form of data collected by A. Hrdlicka in 1940) (Giles and Elliot 1963:68).

Through their observations and subsequent tests, Giles and Elliot concluded that "these discriminant functions provide an adequate means for sexing American Indians [Native Americans]" (Giles and Elliot 1963:66-67). The accuracy in sex determination of Native American crania when using the "black-white" sectioning point (derived from the reference skulls of the Terry and Hamann-Todd Collections) was equal to the accuracy achieved when the Native American sectioning point (representing their own means) was employed. Only the Florida series of Native American skulls showed variations in accuracy when different sectioning points were applied (Giles and Elliot 1963:67). Morphological considerations witnessed especially in females of the Florida Native American series (such as large and long-headed characteristics) may explain the misclassification of these specimens when the "black-white" sectioning point was used (Giles and Elliot 1963:67). Further tests on "chimpanzee, early Irish and American Indian [Native American] crania" were conducted by the authors, the results of which were stated as substantiating the power of discriminant functions analysis to accurately estimate the sex of an unknown specimen (Giles and Elliot 1967:67). The authors express their confidence in the universality of their discriminant functions by emphasising the fact that the functions are applicable to all populations, if "proper adjustment is made to the sectioning point in each circumstance" (Giles and Elliot 1967:67).

RACE DETERMINATION

"White", "Black" and "Indian" were the three taxa of "races" assigned to the test crania used by Giles and Elliot in their 1962 study of race determination by discriminant functions analysis. The eight cranial measurements employed to help diagnose race were the glabella-occipital, basion-bregma, basion-nasion, basion-prosthion and prosthion-nasion lengths in addition to bizygomatic, prosthion-nasion and cranial breadths.

From these eight measurements, two discriminant functions for the diagnosis of race were formulated. As described by Snow *et al.*:

> "The first discriminant function (DF) assigns the specimen a DF score along a 'White-Black axis', the second assigns a DF score along a "White-Indian axis". Using the 'White-Black axis' as the *ordinate*, and the 'White-Indian axis' as the *abscissa*, the scores are plotted on a graph divided into 'White', 'Black' and 'Indian' zones by the DF sectioning points. Race is determined by the zone within which the point plotted for the unknown specimen falls. The procedure is used to determine the race of crania of both sexes. However, the weighting coefficients of the measurements used to determine race for males differ from those used for females."
>
> (1979:449)

In *An Evaluation of Race and Sex Identification (1966),* W.H. Birkby puts the Giles-Elliot Discriminant Functions to the test. Using the same methods and procedures outlined in the Giles-Elliot studies on race and sex determination (1962;1963), Birkby sets out to investigate the "universal applicability" of the authors' deduced discriminant functions by using them to determine the race and sex of Native American populations which Birkby considers to be "non-representative" in the original Giles-Elliot study. Birkby also attempts to determine whether discriminant functions analysis results in a significant increase in accuracy compared to race and sex determination based upon visual inspection of non-metric traits alone. Using Giles and Elliots' discriminant functions, Birkby attempts to identify 104 Native American and Labrador Inuit crania of known sex. The accuracy rate for sex determination ended up being higher for male skulls than for female skulls whose sex was incorrectly determined up to 50% of the case specimens. The highest inaccuracy in sex determination involved the sex estimation of non-deformed Palus Native North American skulls in which the sex of 80% of the female skulls was inaccurately determined (Birkby 1966:23-27). Birkby surmises that discriminant function analysis (as evidenced by the results from his test samples) does not provide a significant increase in accuracy compared to sex determination based on non-metric traits (Birkby 1966:23-27). In terms of race determination, Birkby records that 35.6% of non-deformed crania were inaccurately identified by the DFA, which ended up classifying the skulls as being Caucasoid or Negroid. Deformed skulls were even less likely to be classified correctly, with 60% of the deformed test crania being misclassified (Birkby 1966:23-27). Birkby attributes these inaccuracies to two primary factors, the first being that discriminant functions analysis is applicable only to samples of osteological material which are of the same race(s) as the individuals comprising the reference populations upon which Giles and Elliot based their original discriminant functions. He underlines the fact that the conclusions drawn by the authors, based on what Birkby believes are relatively small, and "non-representative" collection of skeletal specimens and equally biased and inaccurate discriminant functions do not qualify or substantiate the authors claim that their discriminant functions are universal representation of the morphology, variation and metric characteristics of all individuals in the United States, for " in order to be able to sex and race on a U.S.-wide basis, it is required that the American White [Caucasians], Negro and Indian [Native American] sample upon which the discriminant functions are based is representative of the population in question [so as that they are] inclusive of all Whites, Negroes and Indians" (Birkby 1966:27). He underlines that it is highly doubtful that the Caucasoid, Negroid and Native American crania employed by Giles and Elliot as the basis of their discriminant functions scores can be considered as comprising such an "inclusive" sample scheme. This fact is clearly illustrated by the evidence provided by Birkby's further analysis of the Native American samples employed by Giles and Elliot, particularly the Indian Knoll crania which cannot realistically serve as a representative "type specimens" to which all Native American specimens are to be compared to due to the obvious differences in cranial dimensions expressed in the Indian Knoll population. In addition to this fact, other authors have pointed out problems pertaining to secular changes which have resulted in morphological changes such as the higher mean skull height of Caucasians than Native

Americans, thereby "[making] the Giles-Elliot "White-Indian function" weigh skull height in the wrong direction for modern Native Americans and Whites" (Reichs 1998:447-448).

BY CALIPERS AND COMPUTER: THE INTRODUCTION OF COMPUTER-BASED ANALYSIS TO SEX AND RACE DETERMINATION IN FORENSIC RESEARCH

In 1979, Snow and colleagues formulated a test to determine the answers to two specific questions: Firstly, do the Giles-Elliot discriminant functions render the same level of accuracy when applied to actual forensic specimens as they do in tests conducted on skeletal collections of known sex and race? Secondly, can individuals with no background in physical anthropology match the accuracy rate in sex and race determination of an experienced anthropologist, using only the osteometric tools of the trade (calipers) and a computer program loaded with the discriminant functions needed for discriminant functions analysis?

Although this study would end up substantiating the inapplicable nature of the discriminant functions that Giles and Elliot obtained from measurements taken from "nonrepresentative" populations such as the Native American specimens from Indian Knoll, it succeeded in highlighting the potential of computer technology in the field of forensic identification. Freed from the burden of hand-computation, the relative ease and simplicity of the computer Discriminant Functions Analysis (DFA) led the researchers of the study to support the idea that non-anthropologists (such as law enforcement agents and individuals involved in other facets of the medicolegal profession) would be able to use the system to identify unknown crania with a reasonable level of accuracy (Snow *et al.* 1979:448-460). Tests such as those of Snow and other physical anthropologists of the 1960s and 1970s would serve as models for the inevitable incorporation of new methods and technology, (particularly computer technology) into the field of physical anthropology. One of the most significant research advances has been witnessed in the past few years with the launch of one of the largest collections of modern skeletal information which rivals the collections of the past in its ability to provide a multitude of data, at the touch of a button.

THE DIGITISATION OF OSTEOLOGICAL INFORMATION: THE FORENSIC DATA BANK - THE *COMMERCIUM CRANIORUM* OF THE 1990S

Physical anthropologists have never quelled the desire to gather osteological information considered to be germane to their own line of research. In the early 1900s, the *Commercium Craniorum* was the "Gibraltar's Market" for osteological material (particularly crania) barteredand exchanged between colleagues. In light of the effects of secular changes and pathological conditions, today's researchers are more selective in choosing the samples which will make up their test samples. Gone are the days when an anthropologist in need of skeletal information could turn to reliable, "standard"reference collections, such as the Terry and Hamann-Todd Collections used by past colleagues, as recent studies of several anthropologists have classified both of these collections as being non-representative of "contemporary" populations. Taking into consideration the fact that the individuals comprising these skeletal collections were born during the mid to late nineteenth century and originated from (more or less) a common geographical area, it is clear to see why the collections have been dubbed as being "biased both demographically and biologically" (University of Tennessee 1999). Evidenced by discrepancies and inaccuracies that have stemmed from discriminant functions based upon data gathered from skeletal material belonging to said collections, it is equally easy to understand why anthropologists, particularly those in the field of forensic anthropology, would voice the need for more "contemporary" reference collections of human osteological material. Such collections would serve both as central sources for data gathering and as testing grounds for new techniques in forensic identification.

Through the collective efforts of several American anthropologists, (notably L. Angel, S. Rhine and D. Ubelaker), the idea sprang forth to create a modern, accessible computer-based data bank to service the needs of all forensic anthropologists by providing them with osteological and osteometric data derived from more "contemporary" skeletal material. Under the leadership of R.L. Jantz, and supported by funding from the National Institute of Justice and W.M. Bass, the dawn of the computer-age *"Commercium Craniorum"* was set to motion on September 1, 1986. The data base was first loaded with measurements taken from skeletal collections housed at the University of Tennessee, University of New Mexico and Arizona, however, because the basis of human identification rests upon information pertaining to age, ancestry, sex and stature, a general call for "submissions" of forensic data was put out to all forensic anthropologists. Attempts to improve the accuracy of data recording resulted in the publication of the data collection handbook entitled*: Data Collection Procedures For Forensic Skeletal Material (1994)* by Moore-Jansen, Jantz and colleagues. As of 1998, the compilation of all forensic data has increased the volume of documented skeletal information in the Forensic Data Bank to a total of 1,332 documented cases of which 1,019 cases are of known race and sex. The data recorded from these cases ranges from metric to non-metric information derived from both cranial and post-cranial elements. In addition to twenty-four craniometric measurements following Martin (1956; 1957), the data bank has files which include demographic data, information on the status and weight of each case specimen and a variety of other information, including circumstances surrounding death (Reichs 1998:492). The wealth of data provided by the Forensic Data Bank (FDB) offers several benefits to those involved in forensic research and medicolegal investigations. There are primarily four major advantages offered by the skeletal data of the FDB, the most obvious one being that the data bank consists of more "contemporary" skeletal samples. Although some skeletal data from skeletal material belonging to the Terry and Hamann-Todd Collections have been included in the FDB (mainly individuals born after 1898), the specimens included in the FDB are approximately 30 years younger than the average age at death of the individuals comprising the Terry and Hamann-Todd Collections. Thus, the FDB is more representative of young adults, with the mean age of the FDB paralleling the mean age of the FDB forensic cases (38.2 years), compared to the 54.9 mean age of the Terry collection specimens (Reichs 1998:443). An advantage to the inclusion of the Terry and Hamann-Todd specimens in the FDB is the osteological information such collections provide to researchers studying secular changes and biological changes in populations resulting from immigration and gene flow (The University of Tennessee 1999). The preservation and taxonomy of information in the Data Base also ensure the integrity and convenient availability of data for future studies. Lastly and most importantly in light of the topic at hand, research facilitated by the Forensic Data Bank aids in the development of new techniques for the determination of age, sex and ethnic affinity which is facilitated by the formulation of new discriminant functions for analysis based on Data Bank information.

FORDISC 2.0: PERSONAL COMPUTER FORENSIC DISCRIMINANT FUNCTIONS

Probably one of the most promising innovations to be conceived from the plethora of osteometric information comprising the files of the Forensic Data Bank is FORDISC, a computer program specifically designed to aid physical anthropologists and law enforcement agencies in the identification of human remains. As described by its creators, University of Tennessee anthropologists S. D. Ousley and R. L. Jantz, "FORDISC is an interactive DOS computer program which classifies an unknown adult cranium based on known samples using various cranial and post-cranial measurements" (Ousley and Jantz 1996:1).

The primary usage for the FORDISC program is as a tool to help determine the sex and race of an unidentified individual, which is accomplished by entering specific cranial and postcranial measurements into the computer program. The program then runs complete discriminant functions analysis of the data, based on the discriminant functions derived from the FDB and loaded within the software. The convenience and efficiency of computations and analysis is a vast improvement on the hand-computed methods of just thirty years ago. Ousley and Jantz have also succeeded in tailoring the FORDISC program to fulfill the specific needs of the forensic anthropologist. Specifically, the FORDISC program allows for "the generation of custom ancestry and sex discriminant functions for special requests....", such as the creation of special functions "that are necessary when a specimen is fragmentary and measurements required by published functions, for example Giles and Elliot (1962, 1963) or Jantz and Moore-Jansen (1988) are impossible to obtain" (Ousley and Jantz 1996:1). The FORDISC program is promoted as having the capability of classifying an unknown skull using any combination of cranial measurements. The power to identify human material is made possible by the multivariate discriminant functions which make up the program, and the inclusion of population reference samples belonging to the Forensic Data Bank, and discriminant functions of various populations originally compiled by W.W. Howells (1973). Ousely and Jantz have also made certain improvements to the calculations of living stature. New equations have been formulated for the estimation of "forensic stature" which have been based upon information (in the form of medical records and drivers' licenses) of the deceased recorded in the FDB. Both authors believe that their new method of estimating stature is superior to the methods employed by Trotter and Gleser (1952; 1958) to determine stature in light of the fact that previous equations for stature were based upon cadaver lengths taken from individuals belonging to the Terry collection. Again, the fact that the data gathered from collections which are no longer representative of modern populations due to secular changes render such techniques as inaccurate and inadequate methods of human stature estimations.

The forensic data collection guide (Moore-Jansen *et al.* 1994) was issued with the hope of maintaining the standardisation of osteological measurements and ensuring that the expanding data bank classifies only accurately recorded skeletal data. The necessity to address this issue was brought to the forefront by the re-analysis in recent years of past studies and the discovery of inconsistencies and inaccuracies stemming from incorrectly gathered measurements. Examples of such cases include the inaccurate measurement of the tibia by Trotter (Moore-Jansen *et al.* 1994) and Iscan's inaccurate measurement of distal epiphyseal length (Ousley 1995).

FORDISC 2.0 was made available in 1996 as a newly updated version of the original FORDISC 1.0 program. In addition to the expected technological improvements to speed andgraphics, Ousley and Jantz have also extended the forensic identification capabilities of the original FORDISC program. In his review of FORDISC 2.0, Ubelaker (1998) describes how the authors have expanded the features of the program by including mandibular measurments and functions, worldwide cranial data published by Howells in addition to data bank post-cranial measurements (which allow for the calculation of not only sex and ancestry but living stature as well). Technological improvements include improved graphic quality through a Windows-based format, the utilisation of an enlarged data bank and improved on-line help including a pictorial measurement guide (Ubelaker 1998:128-133).

The obvious curiosity spurred by the suggestion that computer software can be created and programmed (with the data of more "contemporary" reference skeletal populations and the integral multivariate discriminant functions and equations necessary for sex and race determination) to accurately determine the sex and racial ancestry of unidentified skeletal material has presently led to a battery of experiments to test the actual potential of the system. Encouraged by the easy-to-use reputation attributed to the FORDISC 2.0 program, a test was conducted by the author for the purpose of examining some of the questions regarding the accuracy and feasibility of computer-based analysis as it is applied within the field of forensic anthropology.

TESTING FORDISC 2.0'S ACCURACY OF SEX AND RACE DETERMINATION BASED ON DISCRIMINANT FUNCTIONS ANALYSIS ON THREE GROUPS OF CRANIA

The main purpose of this test experiment was to determine the accuracy and applicability of computer programs, such as FORDISC 2.0 as applied to the field of human forensic identification. By conducting this experiment, the author intended to address and evaluate four concepts and queries: 1) The process of taking standardised cranial measurements and the difficulties (if any) encountered during the process of gathering craniometric data; 2) The configuration of the computer program and its level of difficulty (for first time users), with emphasis on analysing some of the more obvious advantages and disadvantages of the program; 3) the overall accuracy of sex and race determination of the test crania as estimated through the process of discriminant functions analysis; and finally 4) an overview of some of the factors contributing to misclassification such as the ambiguity surrounding the concept of "race", "ethnic affinity", and other logistic conundrums that are inherent in statistical studies and interpretations of this nature.

Materials

All of the crania used in this test experiment were obtained from various research collections belonging to the Faculty of Anthropology at the University of

Western Ontario. Access to these specimens was made possible through the kind permission of Dr. C. White, Dr. M. Spence, and Graduate students A. Dolphin and J. Parish. For the purposes of identification, the "groups" of crania measured in this experiment were designated as Group A, Group B and Group C. **Group A** refers to 6 crania (figures 1 and 2) of undetermined sex referred to as being of "Asian descent" (White 1999).

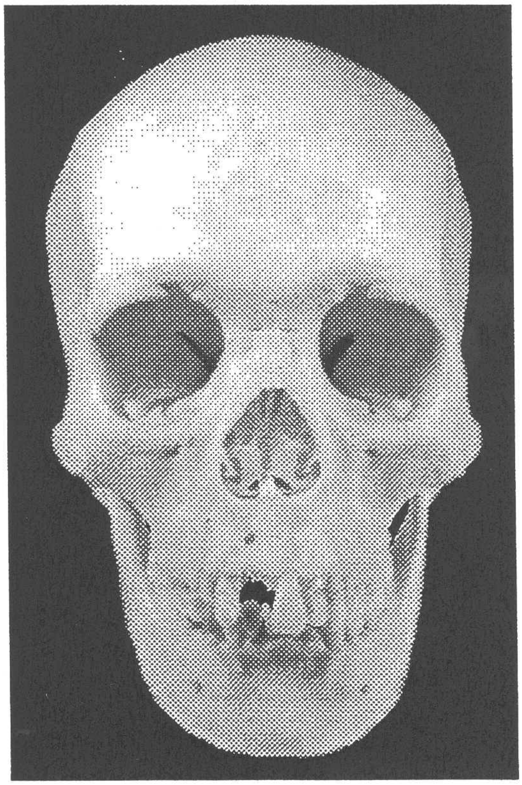

Figure 1. Cranium #1 represents characteristics of the female sex. Age is undetermined. This individual is of "Asian ancestry".

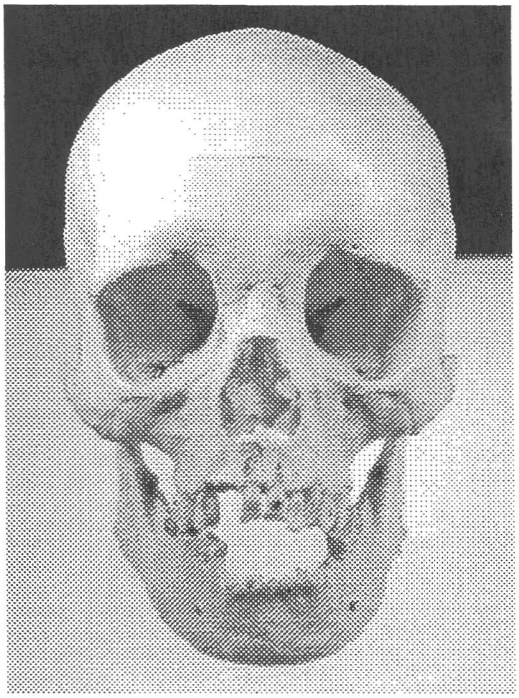

Figure 2. Cranium #4 indicates all of the major male characteristics with the exception of the obtuse gonial angle that is a female attribute. This individual is of "Asian ancestry".

Because specific information pertaining to the sex, age and race of these crania was lacking, the sex of the crania in question was arrived at through visual inspection of cranial non-metric traits. The inspection was conducted in adherence to the identification of particular diagnostic character traits that are recognised as facilitating the prediction of sex from the observation of human cranial morphology. These features include: For males, evidence of prominent supra orbital tori, blunt supra orbital ridges, large mastoid processes, and a prominent External occipital protuberance. Zygomatic crests extending beyond the external auditory meatuses, and a sloping forehead are "typically" male traits, as is a robust mandible, large teeth (compared to female dentition), a U-shaped palate and more gonial eversion (White 2000:362-365). Female attributes include more gracile features, a vertical forehead, no prominent supra orbital tori, sharp supra orbital margins and small mastoid processes. A more delicate-looking mandible with no evident mental eminence (trigonium), a parabolic palate and obtuse gonial angle of more than 90 degrees are diagnostic of the female sex (White 2000:362-365).

Twenty-four cranial measurements, as delineated and described by Moore-Jansen *et al.* (1994), were recorded for each cranium. Table 1 is an illustration of the typical "data sheet" compiled for each skull. In addition to the raw metric data recorded for each specimen, a summary of the morphological features of each skull was recorded, along with observations regarding the general condition/state of the specimen studied.

Traits		***Tools***	***Measurement (mm)***
1. Maximum Length	(GOL)	spreading calipers	187
2. Maximum Breadth	(XCB)	spreading calipers	138
3. Bizygomatic Breadth	(ZYB)	spreading calipers	124
4. Basion-Bregma Length	(BBH)	spreading calipers	128
5. Cranial Base Length	(BNL)	spreading calipers	100
6. Basion-Prostion Length	(BPL)	spreading calipers	98
7. Max. Alveolar Breadth	(MAB)	spreading calipers	N/A
8. Max. Alveolar Length	(MAL)	spreading calipers	55
9. Biauricular Breadth	(AUB)	sliding calipers	119
10. Upper Facial Height	(UGHT)	sliding calipers	65
11. Minimum Frontal Breadth	(WFB)	sliding calipers	96
12. Upper Facial Breadth	(UFBR)	sliding calipers	101
13. Nasal Height	(NLH)	sliding calipers	49
14. Nasal Breadth	(NLB)	sliding calipers	28
15. Orbital Breadth	(OBB)	sliding calipers	39
16. Orbital Height	(OBH)	sliding calipers	35
17. Biorbital Breadth	(EKB)	sliding calipers	95
18. Interorbital Breadth	(DKB)	sliding calipers	23
19. Frontal Chord	(FRC)	sliding calipers	112
20. Parietal Chord	(PAC)	sliding calipers	116
21. Occipital Chord	(OCC)	sliding calipers	96
22. Foramen Magnum Length	(FOB)	sliding calipers	33
23. Foramen Magnum Breadth	(FOB)	sliding calipers	28
24. Mastoid Height	(MDH)	sliding calipers	25

Skull Number: #18	***FORDISC 2.0***	***Howell's Analysis***
Actual Sex: Female	Estimated Sex: Female	Estimated Sex: Female
Actual Race: Caucasian	Estimated Race: Black	Estimated Race: Norse
Age: early- mid 80's		

Table 1. Example datasheet of cranial measurements and results of discriminant functions analysis compiled for each specimen.

Group B refers to a collection comprised of 5 skulls (4 males and 1 female) of Maya ancestry (figures 3, 4). These skulls were also observed visually for the purposes of sex determination, the results of which were compared to sex and age determination data provided by A. Dolphin. The Maya skulls are those of individuals living in the Post-classic period and are from the San Pedro site in Belize (Dolphin 1999).

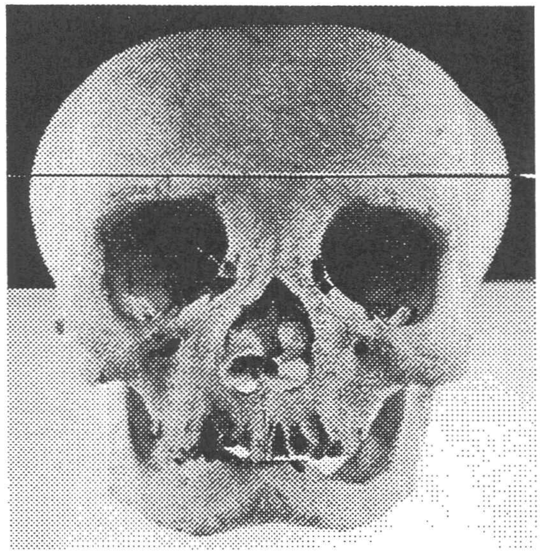

Figure 3. The cranium of SP 11-2/1 is that of a Maya male of unknown age.

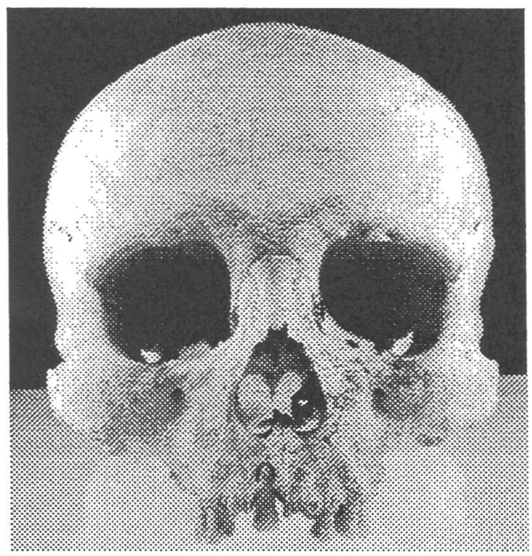

Figure 4. The cranium of SP 11-2/4a is that of a Maya male of over 40 years of age.

The incorporation of these skulls in the test experiment was meant to serve two main purposes: First, to observe how the FORDISC program analyses, interprets and classifies crania that are culturally modified (such as those included in this group); Second, to ascertain how the program interprets prehistoric cranial material and more specifically, how it deals with classifying the race of individuals belonging to an ancient population.

Group C consisted of 5 skulls (3 males and 2 females) classified as being Caucasian individuals mainly of British descent (figures 5, 6) buried between A.D. 1840 and A.D. 1890 (Cook *et al.* 1986:107). Access to historic material and information on this collection was provided by J. Parish

As described by Cook *et al.* (1986:107-116), these crania belong to a larger collection of individuals (27 in total) which were interred in a local community cemetery. The skulls were discovered "...in the fall of 1982, by contractors excavating a house's foundation at Stirrup Court, in Northwest London" (Cook *et al.* 1986:107). Included in Group C, (but not belonging to the Stirrup Court population) is the only Negroid cranium included in this study (figure 7). The skull, identified by the individual's real name, "Mr. Jackson", also had historic documentation. Mr. Jackson was executed by hanging, and in newspaper accounts he is described as being a "coloured male".

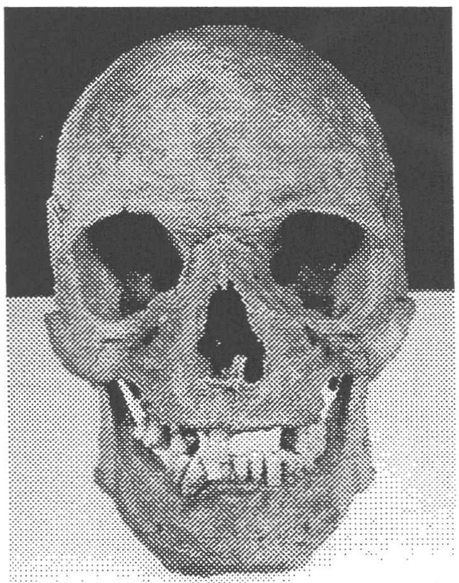

Figure 7. "Mr. Jackson" represents the only available Negroid cranium that was included in this study. Note the extensive damage to the left side of the cranium. This particular skull does not belong to the Stirrup Court collection but was included in Group C solely for the purposes of sorting material and taxonomising raw data and results.

Further analysis of this skull has confirmed the presence of shovel-shaped incisors, possible evidence that Mr. Jackson may have been of Native American heritage as well. Skull #20 belonging to the Stirrup Court collection also has shovel-shaped maxillary incisors and has been classified as exhibiting phase 2 double shoveling and phase 3 shoveling based on the Arizona State casts (Parish 1999).

Method

Cranial measurements were based upon the list of 24 measurements as defined in Moore-Jansen *et al.* (1994:49-57) and included in the menu portion of FORDISC 2.0. Great care was taken in becoming acquainted with the nomenclature, landmarks and measurements prior to data collection. The following is a summary of some of the challenges confronted while attempting to record the necessary cranial measurements for analysis. Deformed skulls (such as the culturally modified Maya skulls) and damaged crania proved to be the most difficult to measure. Broken zygomatic arches affected the measurement of bizygomatic breadths, broken occipital bones and foramina magna resulted in the inability to measure basion-bregma lengths and cranial base lengths, while notches in orbits affected the measurement of orbital height. Alveolar degeneration (edentulous maxillae) hindered measurements such as alveolar breath and any measurement having the prosthion as a reference point. Obliterated sutures (coronal, sagittal, lamdoidal, zygomatico-temporal sutures, nasion) and other signs of aging made it difficult to take measurements such as the frontal, parietal and occipital chords as well as nasal length. Non-metric traits such as wormian bones made it difficult to discern the exact point of intersection of the sagittal and lambdoidal sutures which distinguish the location of the lambda.

Data Input

After all raw data were collected, measurements were entered into the FORDISC program. Included with the program is a concise, easy to read FORDISC users manual. In general, it must be noted that the program was (from a technical standpoint) quite comprehensible, accessible and easy to use. The main menu lists the 24 cranial measurements required for analysis. For the sake of convenience, spaces are provided beside each "measurement label" for the entry of raw data (cranial measurements) that are recorded in millimeters. Important measurements that are believed to be responsible for reducing the size of the reference group are shown in blue or red text (instead of ordinary black text). Ubelaker notes that "In the test case, processing with these [colour-coded] measurements gave the same results as processing without them, suggesting that the reduced sample size does not change the outcome" (Ubelaker 1998:128-129). One positive feature of the program is that it occasionally double-checks data that doesn't appear to be quite correct (compared to normal values). This occurred several times when the cranial breadth and bizygomatic measurements for the culturally modified Maya skulls were entered. Thus, this feature serves as a good safeguard against the processing of incorrect data resulting from measurement errors or data entry errors. Data entry is followed by the selection of groups to be included in the analysis. This is achieved by checking the box beside the appropriate race. The FDB's "racial categories" are listed as: White Male, White Female, Japanese Male, Japanese Female, Black Male, Black Female, Amerind Male, Amerind Female, Chinese Male, Hispanic Male and Vietnamese Male. Unfortunately, there is no explanation as to why the female counterparts to the last three "races" are not included in the list.

Discriminant functions analysis of the raw data entered commences by clicking on the "Process Now" icon. Within a few minutes, the results for sex determination are displayed by way of a table specifying group, total number and percentage correct. A second table lists the aforementioned "races" (in abbreviated form) under the category of "Group". Numerical values listed beneath column titles indicating biological distance and probabilities are shown and the race and sex that the specimen most closely "matches" are highlighted by an asterisk beside an abbreviated form such as WM (White Male) (tables 2, 3). The results may also be viewed as a bar graph in which the sectioning point separating males and females is clearly defined (figure 8).

Group	Total Number	Into Group WM	WF	BM	BF	AM	AF	JM	JF	HM	CHM	VM	Percent Correct
WM	168	121	17	1	0	3	1	4	0	10	9	2	72.0%
WF	132	11	104	1	3	0	1	0	4	7	0	1	78.8%
BM	126	8	2	68	17	2	6	7	2	9	4	1	54.0%
BF	107	1	5	10	80	0	0	0	8	3	0	0	74.8%
AM	46	0	0	0	0	32	5	1	2	0	5	1	69.6%
AF	28	0	1	1	0	3	17	0	2	1	1	2	60.7%
JM	100	2	0	10	1	10	0	44	10	7	12	4	44.0%
JF	100	0	5	4	9	0	4	8	56	6	3	5	56.0%
HM	37	5	1	2	2	1	1	2	0	19	3	1	51.4%
CHM	79	1	0	6	0	0	8	6	1	5	50	2	63.3%
VM	51	0	1	1	0	0	0	2	2	0	6	39	76.5%
Total:	974					Correct: 630							

Table 2. Discriminant function results using sixteen variables using FORDISC 2.0. Abbreviations in the columns represent the male and female groups used in the discriminant functions analysis for the specimen.

Group	Classified into	Distance from	Probabilities Posterior	Typicality
WM	** WM **	15.6	.852	.483
WF		20.9	.058	.180
BM		23.9	.013	.092
BF		31.1	.000	.013
AM		23.7	0.15	.097
AF		23.0	.020	.113
JM		24.6	.009	.077
JF		31.8	.000	.011
HM		22.5	.027	.128
CHM		26.4	.004	.048
VM		31.2	.000	.013

is closest to WMs

Table 3. A multigroup classification of test specimen using FORDISC 2.0. These results predict that this individual is estimated to be a white male (WM). The specimen used here is Stirrup Court #4.

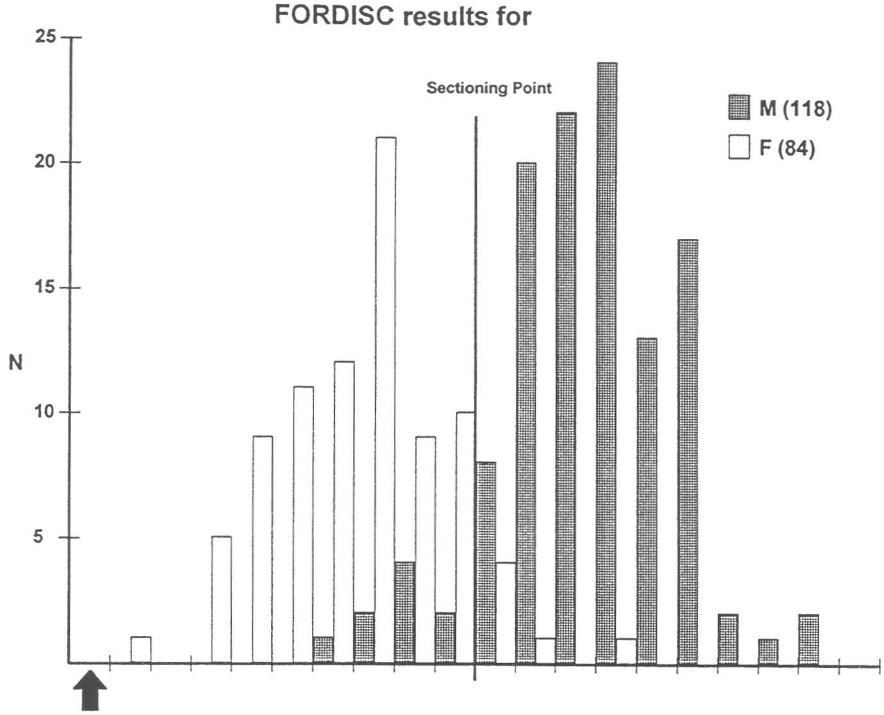

Figure 8. An example of FORDISC 2.0's graphical representation of sex determination by discriminant function analysis. Note the arrow the line indicating the sectioning point and the arrow showing where the DFA values of the predicted female specimen have fallen (in terms of the male/female schism). Results shown are for the DFA of Asian skull #1.

Howells' data comes from craniometric analyses documented in his well-known book Cranial *Variations In Man* (1973). A re-analysis of the raw data may be initiated by pressing the "Re-analyse" icon. Clicking the icon for "Howells' Populations" brings up a screen listing 28 different populations. As in the process for sex determination, the applicable "ethnic populations" (and corresponding functions) to be included in the analysis may be selected by "check-marking" the appropriate icons located beside each population title. The discriminant functions analysis employing Howells' populations takes a lengthier amount of time to process data (up to five minutes per specimen). The discriminant functions results include information on the number of variables used, and lists data taxonomised in three separate columns. The first column displays the abbreviated forms of the populations analysed, the second column presents numeric values corresponding to biological distance, while the third column lists statistical probabilities.

Based on the analysis and results obtained from Howells' discriminant functions analysis on the data provided, certain concerns about the intelligibility and validity of the data soon emerged. To an individual who has a limited knowledge of different "ethnic categories" and historic populations such as knowing that Zalavar refers to individuals of Western Hungarian origin living during the ninth and tenth century (Uberlaker 1999:129), discerning the populations included in the analysis can prove to be challenging without the necessary historic background at hand. Secondly, as no information regarding the sampling size of these populations is made known (at least on "screen"), it is difficult to ascertain how representative the populations in question actually are without having to consult additional references. Furthermore, canonical plots representing some of the results of the multivariate discriminant functions analysis on certain individuals are unintelligible and close to impossible to read. Though an asterisk designates the "ethnic group" that the specimen is predicted as belonging to, from a visual standpoint (that is, without looking at the corresponding data), it's difficult to discern why a specimen is designated to one group when there clearly seems to be overlap into other groups.

Figure 9 represents an extreme example of one such chart which would challenge even a knowledgeable observer in rendering a convincing interpretation of the data depicted and devising a plausible justification for the resulting classificatory conclusion.

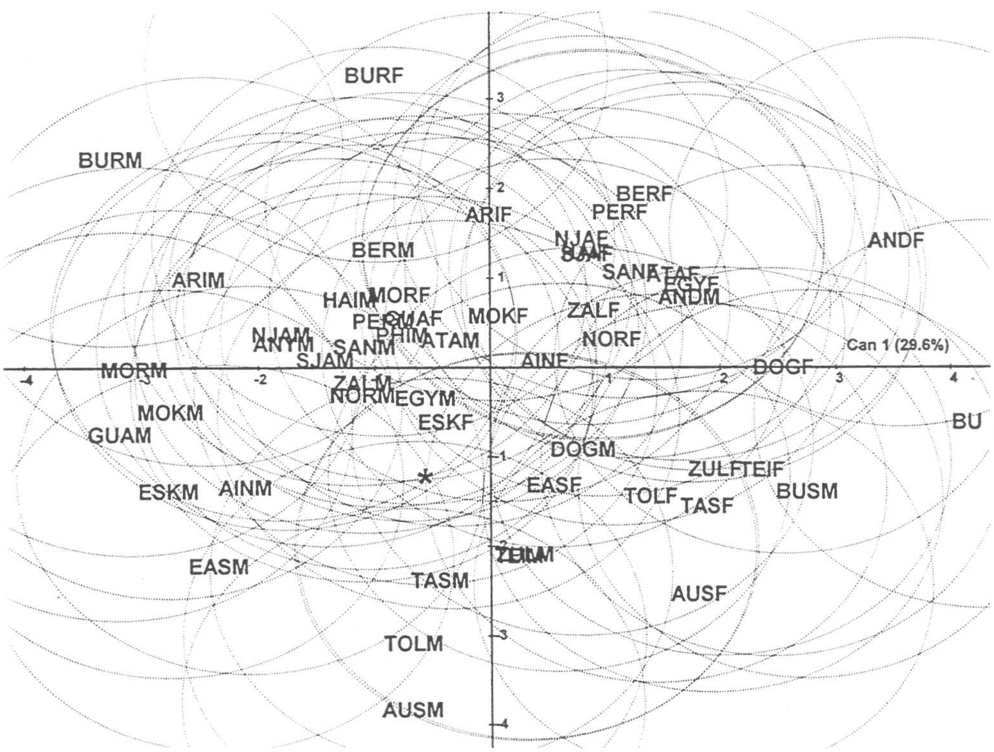

Figure 9. A canonical graph of race determination based on Howells' DFA conducted on Stirrup Court specimen #6. This graph is an example of the difficulty in justifying the classification of a specimen as belonging to a particular group over another in light of the ambigous nature of the depicted results.

Problems arise when the Forensic Data Bank discriminant functions predict a certain group and race and the multivariate discriminant functions of Howells designate the same specimens to another "race". It is understandable if the FDB analysis classifies a skull as White Caucasian male and Howells' discriminant functions designate the skull as being a Norse male seeing as both are consistent with Caucasian ancestry (as is the case with Stirrup Court specimen #20). However, there is no simple or logical "interpretive formula" or explanation pertaining to which DFA prediction should be accepted as being "correct" when a specimen is determined as belonging to both sex categories and to two different racial categories (as is witnessed in the DFA of the crania belonging to Mr. Jackson). Should such a result of race determination be dismissed as an anomalous or inaccurate analysis of data or should it be interpreted as signifying the possible identification of a hybrid individual? Ubelaker (1999:129) observes the prevalence of similar logistic inconsistencies within the Howells' data. He notes how one of his test crania was identified as a Zalavar female, however, "the next closest classifications were in order of probability, Egyptian female and Taiwanese female. Surprisingly, the individual was classified closer to a Chinese sample than to other European groups such as Norse". However, one must also take into consideration the logic behind such taxonomy. For example, the fact that other European groups are considered to be "closer" geographically and biologically does not necessarily mean that their cranial morphology will automatically be similar. This, along with the issue of temporal variation in populations and theoretical issues regarding what the numeric figures conceived from biological distance studies convey and *actually mean*, and whether the information they encode is at all significant are but a few examples of some of the major problems with analyses attempting "race" determination and similar studies of this nature.

Results

The term "accuracy" is only applied when the sex of each individual in a group is positively known. Therefore, in all other cases, the term "accuracy" is substituted with the phrase "matching non-metric indicators of sex". The results of FORDISC 2.0's discriminant functions analysis on the three groups of test crania are as follows (Figure 10).

Group A Sex determination (based on the FDB) resulted in 50% "matching non-metric indicators of sex" for the 6 crania in this group, while 0% "matching non-metric indicators of race" was recorded for race determination. However, the ambiguous classification of this group as "Asian skulls", the lack of information regarding the actual "race" and sex of the individual crania comprising this group, makes it difficult to judge the accuracy of the discriminant functions analysis performed on this group of crania. The discriminant functions of Howells' population resulted in 50% "matching the non-metric indicators of sex" and 16.6 % "matching the non-metric indicators of race" (as only skull #10 was designated as being Northern Japanese, representing the closest biological population to the "Asian-designated" crania).

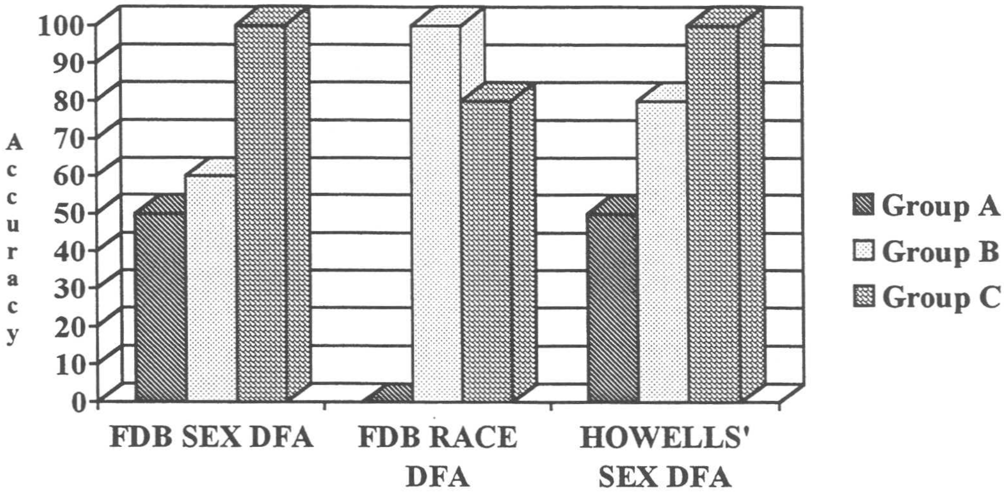

Figure 10. Percentage accuracy of FORDISC 2.0 and Howells' sex and race determination by discriminant functions analysis. Howells' DFA results for race determination have been excluded due to the lack of information regarding the specific origin of some crania used in this study. Group A is of Asian descent, Group B is Maya, and Group C is Caucasian (with the exception of Mr. Jackson who is Negroid).

Group B The accuracy of sex determination for the Maya skulls (based on FDB functions) was 60% for the total group. The FORDISC program classified all the Maya skulls as Amerind, which seems to conform to a more logical estimation of Native American ancestry, as compared to the designation of the skulls to any other "racial population". Howells' analysis faired well in sex determination, resulting in an 80% accuracy rate, while Howells' DFA classified the Maya skulls as being of Berg, Buriat and Ainu ancestry. Questions regarding the representative nature of Howells' populations and the difficulty in classifying crania as belonging to certain specific populations based on the contentious study of biological distancing makes it difficult to comment on the accuracy of the Howells' race determination results in any of the three test groups studied.

Group C The Forensic Data Bank's discriminant functions analysis was successful in "matching non-metric indicators" of sex and "race" of all five skulls (based on the information provided), matching almost all crania to their sex in all cases, except one cranium which was incorrectly identified by the FDB's discriminant functions analysis.

Discussion and Summary

Due to the ambiguity and lack of information regarding the presumed Asian skulls, the challenges of formulating substantiated and justifiable parallels between the specimens studied and Howells' reference populations and the extremely small skeletal sample used, making any sort of generalisation based on the results of the discriminant function analysis conducted on these particular test specimens would be misleading. If pressed to make a final statement, it would be that the FORDISC program seems to have a good chance at accurately determining sex. As for race estimation, the functions seemed to have come close to predicting "ethnic populations" similar to the race of both the "White" British and Maya skulls, however whether this was simply due to chance or whether there is a strong basis to the choice of classification requires far more study, far more measurements to be taken and a far larger group of specimens to analyse. However, the author tends to strongly agree with Rathbun and Buikstra regarding the issue of racial classifications, whose sentiments underscore the fact that "there are few, if any population-specific skeletal or dental features...." and most importantly, that "racial categories are not necessarily biological ones, but instead reflect social or ethnic affiliations" (Rathbun and Buikstra 1984:222).

The conclusions drawn from FORDISC 2.0's DFA analyses bring to light certain contentiousissues regarding the viability and justification of assigning unidentified skeletal remains (in this case, crania) to predetermined conceptual and socially-constructed categories such as "race" and "ethnic affinity". Four major concerns are prevalent when attempting to understand the applicability of such endeavors. Firstly, (regardless of the statistical data provided), one is left to ponder how whether the individuals comprising the Forensic data Bank are truly representative of the population at-large. Secondly, it is quite obvious that such a program will ultimately be challenged when it comes to taking into consideration concepts such as individual biological variation, secular changes, variation attributed to gene flow resulting from migration and morphological anomalies related to pathological conditions, culturally-induced modifications and occupational stress. The third question is of a practical nature. Simply put, is craniometric analysis useful, or can it be seen as a "chicken and the egg question"? This of course refers to the problem of requiring a suitable, "correctly analysed" reference population upon which to test and confirm the accuracy of one's discriminant functions. What remains yet to be answered is exactly how one must go about compiling a well documented, population, whose race and sex have been accurately determined, without first having an accurate, foolproof tool for sex and race determination to assemble the required "well-documented" population of study?

In addition to such cyclical dilemmas, a host of other unresolved issues regarding the interpretation of factors such as individual variability and the contentious subject of the determination of ethnic affinity further compound the difficulty of the various aspects of skeletal identification. Osteologists attempting to determine the age, sex, stature and race of unknown human remains through metric and non-metric means have focused on broadening their knowledge of the specific aspects that influence the assessment of biological qualities. Factors such as age categories, available skeletal elements, sample composition, analytical methods, applicability of the method to the unknown individual or sample and research context have both helped to improve the accuracy and precision of predictions and increase the general understanding of the developmental and degenerative sequences of the human skeleton (White 2000:338). Ironically however, it is the very inconsistencies and interpretive conundrums resulting from some analyses of these factors that end up substantiating the observation of critics who contend that predictions derived from investigations of this nature should be considered as no more than "probability statement [s]" (White 2000:338) rather than solid facts.

More than any other discipline in the realm of scientific anthropological research, craniometric analysis and those involved in the fields of craniology and craniometry have had to live in the shadows of the discipline's less than honourable history. Though osteometric standardisation and methodology have come a long way since the early nineteenth century, the general premise behind craniometry remains the same- interest in the variation of skull shape and dimensions, and the potential of using such variation as a diagnostic marker of sex, race and possibly ethnic ancestry.

In the 1960s Giles and Elliot set the standard for the role of craniometry in sex and age determination. Through their work, mathematical formulae producing some of the first diagnostic numeric values of discriminant functions proved to be a justifiable means of using craniometric data to determine sex and race above and beyond the visual inspection of non-metric traits. With the coming of the computer age, and the growing interdependence of anthropology and statistics, metric analyses and comparative studies using craniometric data have been resurrected as necessary research tools. No two other innovations have exemplified this movement forward as the Forensic Data bank, and FORDISC 2.0, a multifaceted computer program designed to determine sex and race from basic measurements including those of the cranium and post-cranial skeleton. FORDISC osteological data have proven to be "more representative" of contemporary populations compared to "more dated" previously used references, such as the Terry and Hamann-Todd collections that are deemed as inappropriate comparatives to contemporary skeletal material in light of secular changes. The bounty of taxonomised information within the FDB promises to provide the necessary information needed for future studies in physical and forensic anthropology particularly in the development of new aging and sexing techniques which are the integral components upon which advancements in medicolegal applications involving human forensic identification are based. However, what appears to be true in theory isn't always true in practice. Concerns regarding how representative data bases and discriminant functions are is currently being debated, as are discourses regarding the effects of cultural practices, gene flow and pathology (including illness and trauma), the effects of time and forces of nature on human remains which are all factors that influence one's ability to interpret the race, sex and age of human remains beyond a reasonable doubt. Thus, as in every other discipline, extreme caution must be heeded in the interpretation of craniometric data, as is clearly forewarned by Howells:

> "In the later generations multivariate statistics have provided a much better sort of model for variation within and between populations, in the kinds of overlapping groupings which can be detected in a multivariate space. These are satisfying, but we must always inquire how true such fits are. We wish art to imitate nature, but it is up to the anthropologists in particular to see that nature does not imitate art."
>
> (1984:4)

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